

Studies on the site of fat absorption

2 Fat balances after resection of varying amounts of the small intestine in man

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SYNOPSIS This paper demonstrates that in man, as in the rat, increasing amounts of fat reach more distal levels of the small intestine as the dietary load increases.

Opinions have varied as to the site of fat absorption in the small intestine of experimental animals (Bernard, 1856; Frazer, 1943; Kremen, Linner, and Nelson, 1954; Benson, Chandler, Vansteenhuyse, and Gagnon, 1956; Turner, 1958; Booth, Read, and Jones, 1961). It is now clear that the site where fat is normally absorbed depends on the dietary load. When a small amount of fat is given to a rat, for instance, absorption takes place almost entirely in the jejunum. If larger quantities are fed larger amounts are absorbed in the jejunum, but at the same time an increasing proportion of the ingested fat escapes absorption in the upper intestine and passes on into the ileum where absorption then also occurs (Booth *et al.*, 1961).

The site of absorption of fat in man is uncertain. Borgström, Dahlqvist, Lundh, and Sjövall (1957), using an intestinal intubation technique, have claimed that fat is absorbed in the proximal 100 cm. of the jejunum. This finding, however, conflicts with the clinical observation that steatorrhoea may follow resection of the ileum (Cox, Meynell, Cooke, and Gaddie, 1958; Kalser, Roth, Tumen, and Johnson, 1959). It seemed possible that in man, as in experimental animals, the site of fat absorption might depend on the amount of fat fed. In order to test this hypothesis, we have studied fat balances in a group of patients who had undergone resection of varying amounts of the small intestine. The patients were grouped according to whether the proximal or distal small intestine had been resected, since experimental studies in animals suggest that jejunal resection is less likely to disturb intestinal function than resection of the ileum (Jensenius, 1945; Kremen *et al.*, 1954).

Fat balances were first carried out using diets

containing between 30 and 75 g. daily. The results of these balances indicated how much of the small intestine is required to absorb moderate amounts of fat normally. Increasing fat diets were then given to four patients, for if the site of fat absorption is related to the dietary fat, it might be expected that increasing fat diets would cause increasing degrees of steatorrhoea in patients with intestinal resections.

PATIENTS STUDIED

Fat balances were carried out in seven patients who had undergone resection of varying amounts of the distal small intestine (Cases 1 to 7) and two patients who had resections of the proximal intestine (Cases 8 and 9). An approximate estimate of the length of intestine resected in each patient was obtained from the surgical operation specimens and by subsequent barium follow-through examination. Clinical details, including the data from which the extent of the resection in each patient was assessed are given in the Appendix, and the lengths of intestine either resected or assumed to be remaining in the different patients are given in Tables I and II.

MATERIALS AND METHODS

Patients were studied in a metabolic ward. The diets containing from 30 to 100 g. of fat have been described in detail by King and Wootton (1956). Where additional fat was given, it was invariably added in the form of butter fat. The amount of each diet which was rejected was analysed.

ANALYSIS OF FAECAL FAT EXCRETION The methods were those described by King and Wootton (1956). After a preliminary equilibration period of three days on each diet, the stools were collected for two consecutive three-day periods into suitable metal containers. The specimens were first weighed and homogenized and a sample of this

homogenate was then dried. This dried aliquot was treated with hydrochloric acid and extracted with ether, the extracted fat being determined gravimetrically. The mean faecal fat excretion during each of the three-day periods was then calculated. Using this technique, control subjects usually excrete less than 6 g. of fat daily when taking diets containing between 50 and 100 g. of fat.

The difference between the dietary fat and the fat excreted was assumed to be the amount absorbed. While this calculation does not take into account the small amount of fat in the faeces that may be of endogenous origin, it gives a reasonable approximation of fat absorption.

RESULTS

MODERATE DIETARY INTAKES The dietary intakes, faecal fat excretion, and estimated fat absorption from diets containing moderate amounts of fat (between 30 and 75 g. daily) are shown in Tables I (distal resections) and II (proximal resections).

Distal resections The results of the fat balances in the seven patients who had undergone resection of varying amounts of the distal small intestine (Cases 1 to 7) are given in Table I and illustrated in Fig. 1.

Two patients (Cases 1 and 2) had no significant steatorrhoea (Fig. 1); these two patients had lost the ileocaecal valve together with only 6 or 8 ft. of the distal ileum.

TABLE I
FAT BALANCES DURING TWO CONSECUTIVE THREE-DAY PERIODS AFTER RESECTION OF DISTAL SMALL INTESTINE

Case No.	Amount of Intestine Resected	Dietary Fat (g. per day)		Faecal Fat (g. per day)		Fat Absorbed (g. per day)	
		1	2	1	2	1	2
1	6 ft. of terminal ileum	47	49	6.2	4.6	41.8	44.4
2	8 ft. of terminal ileum	64	63	6.1	6.2	57.9	56.8
		98	98	14.0	12.0	84.0	86.0
		150	150	15.0	15.0	135.0	135.0
3	10 ft. of ileum	73	71	9.7	9.5	63.4	61.5
4	Ileum and all but proximal 6 ft. of jejunum	29	31	9.0	11.0	20.0	20.0
		51	54	11.0	15.0	40.0	39.0
		98	98	25.0	18.0	73.0	80.0
5	Ileum and all but proximal 6 ft. of jejunum	47	50	13.0	22.0	34.0	28.0
		98	98	26.0	30.0	72.0	68.0
6	Ileum and all but proximal 4 ft. of jejunum	63	62	23.0	19.0	40.0	43.0
		98	98	26.0	30.0	72.0	68.0
7	Ileum and all but proximal 8 in. of jejunum	30	—	15.0	—	15.0	—

The patients with larger distal resections had steatorrhoea and its degree depended on the extent of their resection. One patient (Case 3), who had undergone resection of approximately 10 ft. of the ileum had mild steatorrhoea, excreting 9.5 and 9.7 g. fat daily during successive balance periods (Fig. 1). Two other patients (Cases 4 and 5), both of whom

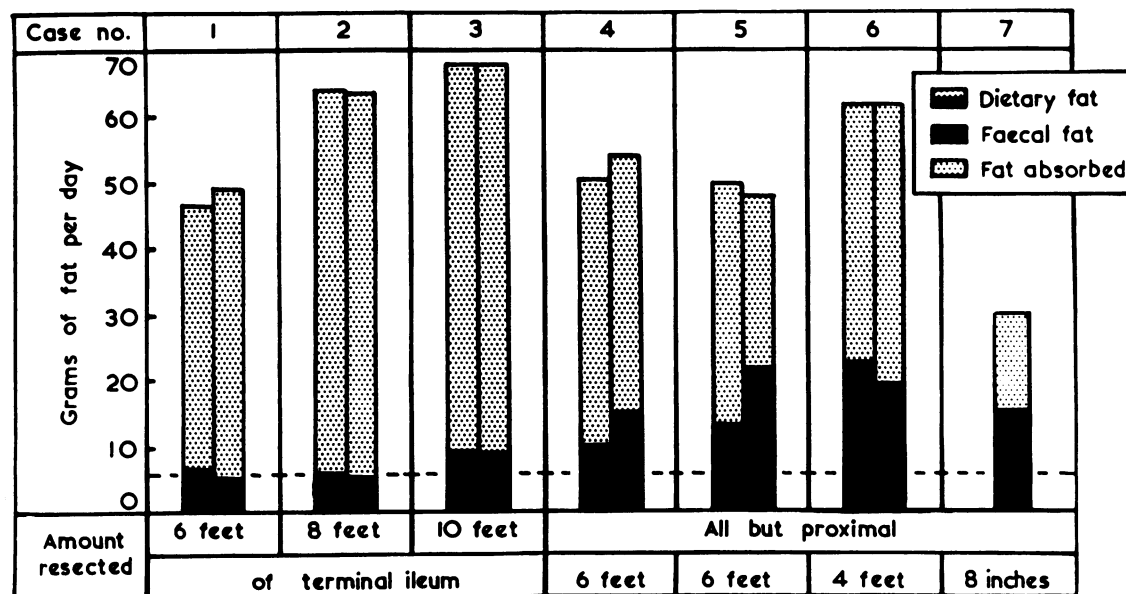


FIG. 1. Dietary fat, faecal fat excretion, and fat absorption (g. per day) during successive three-day balance periods in patients who had undergone resection of varying amounts of the distal small intestine (Cases 1 to 7). The interrupted line indicates the upper limit of normal faecal fat excretion.

had more extensive distal resections, had more marked steatorrhoea; these patients excreted between 11.0 and 22.0 g. of fat daily.

However, even though there might be severe steatorrhoea after a large distal resection, the proximal jejunum was capable of absorbing a considerable proportion of the dietary fat. Although only 4 ft. of the proximal jejunum remained in Case 6, for instance, more than 40 g. of fat was absorbed by this patient from a daily intake of 62 g. (Case 6, Fig. 1, Table I). Furthermore, another patient (Case 7), who had only the duodenum and proximal 8 in. of the jejunum remaining, absorbed as much as 15 g. of fat from a daily intake of 30 g. (Fig. 1, Table I).

Proximal resections The results of similar balances in the two patients who had undergone resection of the proximal small intestine are given in Table II and illustrated in Fig. 2.

The first of these patients (Case 8) had lost the proximal 8 ft. of the jejunum; the daily faecal fat excretion was 6.2 and 6.8 g. during two successive balance periods on diets containing 48.9 and 46.7 g. of fat (Fig. 2, Table II), indicating that most of the dietary fat was absorbed (Table II).

The resection in the second patient was very much more extensive, only 15 in. of the terminal ileum remaining. This patient had moderate steatorrhoea, excreting 12.1 and 13.4 g. of fat daily, but he absorbed more than 35 g. of fat from the short segment of remaining distal small intestine.

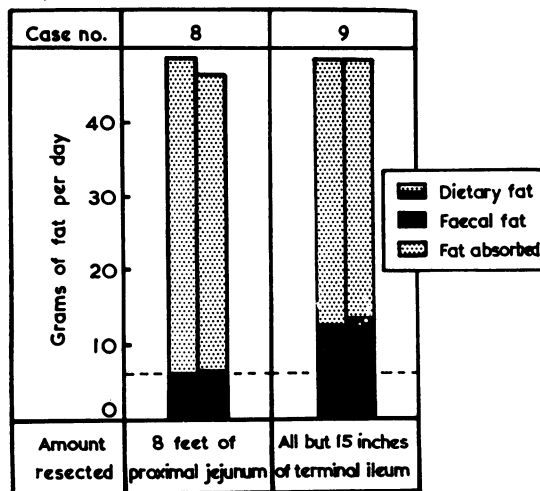


FIG. 2. Dietary fat, faecal fat excretion, and fat absorption (g. per day) during successive balance periods in patients who had undergone resection of the proximal small intestine (Cases 8 and 9). The interrupted line indicates the upper limit of normal faecal fat excretion.

TABLE II

FAT BALANCES DURING TWO CONSECUTIVE THREE-DAY PERIODS AFTER RESECTION OF PROXIMAL SMALL INTESTINE

Case No.	Amount of Intestine Resected	Dietary Fat (g. per day)		Faecal Fat (g. per day)		Fat Absorbed (g. per day)	
		1	2	1	2	1	2
8	8 ft. of proximal jejunum	48.9	46.7	6.2	6.8	42.7	39.9
		98.3	98.0	6.9	7.0	91.4	91.0
		150.0	152.0	5.0	11.4	145.0	141.6
9 ¹	All jejunum and all but distal 15 in. of terminal ileum	48.5	48.5	12.1	13.4	36.4	35.1

¹Balances were carried out during two consecutive four-day periods in this patient.

EFFECT OF INCREASING DIETARY FAT The results of the balances when increasing fat diets were given are also shown in Tables I and II.

Distal resections Increasing fat diets (between 30 and 150 g. daily) were given to three of the patients who had undergone distal resections (Cases 2, 4, and 5). The results of the two successive three-day balance periods on each diet are given in Table I. The mean faecal fat excretion during the total six-day period of each diet is illustrated in Fig. 3, together with the corresponding amount of fat absorbed.

One of these patients (Case 2) had lost only the terminal 8 ft. of the ileum and had no steatorrhoea when taking a diet containing 63 g. of fat daily. However, when the dietary fat was increased to 98 or 150 g. daily, the mean daily faecal fat excretion rose to 13 and 16 g. respectively (Fig. 3, Table I). Although this patient developed steatorrhoea when taking the higher fat diets, the actual amount of fat absorbed increased as the dietary fat was increased (Fig. 3).

The two other patients (Cases 4 and 5) had approximately 6 ft. of the proximal jejunum remaining and both had steatorrhoea when receiving diets containing 50 g. of fat (Fig. 1). One of these patients (Case 4, Fig. 3) was given diets containing 30, 50, and 100 g. of fat daily. As the dietary fat was increased, there was a progressive increase in faecal fat excretion but at the same time the amount of fat absorbed from the remnant of proximal small intestine also increased (Fig. 3, Table I). Similarly in the other patient (Case 5, Fig. 3) there was an increase in both faecal fat excretion and fat absorption when the dietary fat was increased from 50 to 100 g. daily (Fig. 3, Table I).

Proximal resections Increasing fat diets (from 50 to 150 g. daily) were also given to the patient who had undergone resection of 8 ft. of the proximal

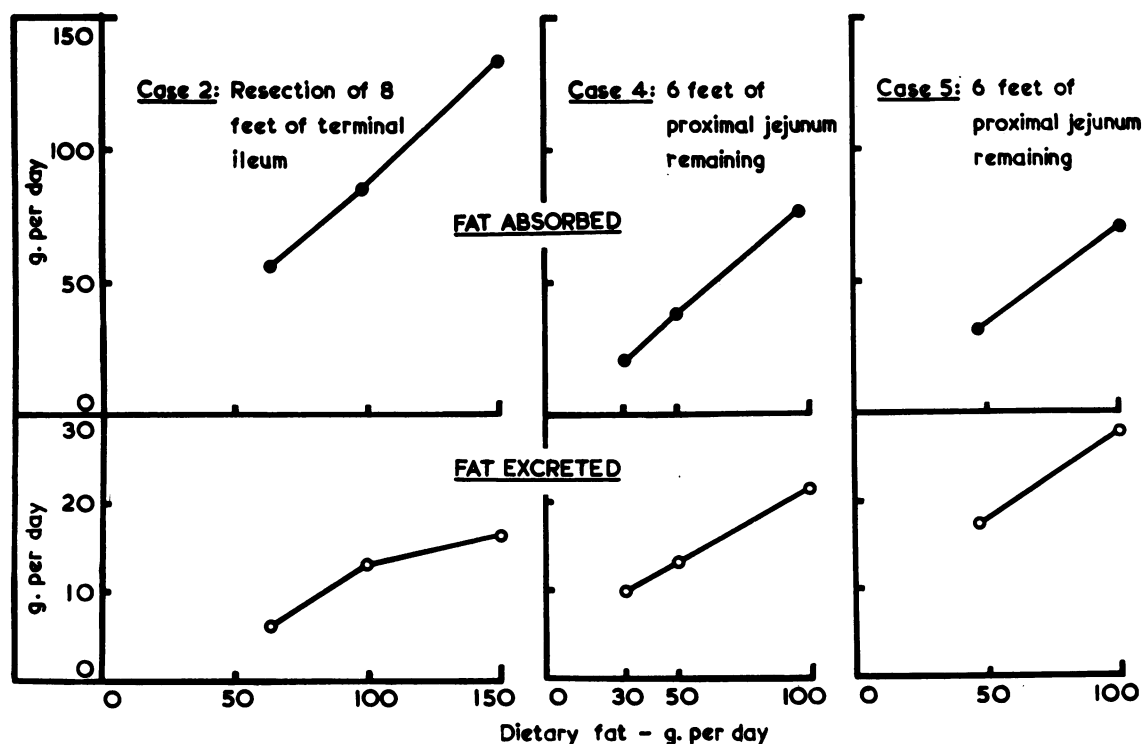


FIG. 3. Effect of increasing fat in diets on fat absorption and excretion in patients with resections of the distal small intestine (Cases 2, 4, and 5).

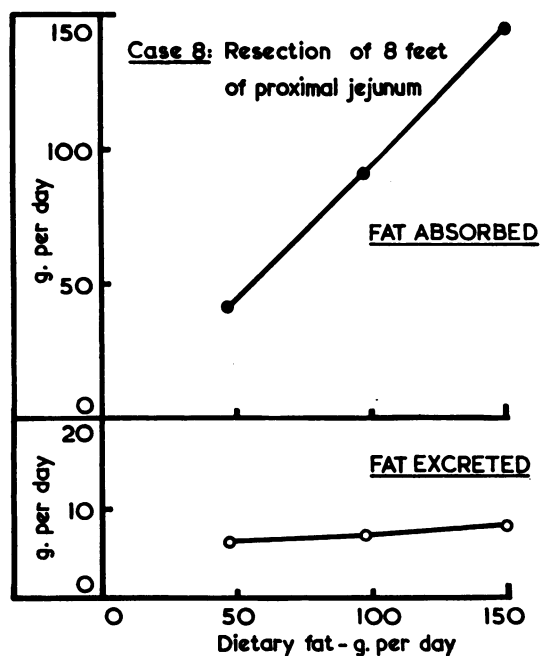


FIG. 4. Effect of increasing fat in diets on fat absorption and excretion.

jejunum. The results of the balances are given in Table II and illustrated in Fig. 4.

This patient excreted a mean of only 6.5 g. of fat daily during the six-day balance when he received a diet containing just less than 50 g. of fat (Fig. 1). When the dietary fat was increased, there was a slight increase in faecal fat excretion (Fig. 4) but the mean amount of fat excreted daily when the diet contained as much as 150 g. of fat was only 8.2 g. As shown in Fig. 4, the amount of fat absorbed by this patient increased progressively as the dietary fat was increased (Table II).

DISCUSSION

The results in the patients subjected to distal resections (Cases 1 to 7, Fig. 1) show that in man the jejunum can absorb fat well. They also indicate that although the proximal ileum may be required for completing the absorption of fat (Case 3, Fig. 1), the distal 6 to 8 ft. do not appear to be necessary when moderate diets are given, even when the ileocaecal valve has been resected (Cases 1 and 2, Fig. 1).

The effects of increasing the dietary fat in three of these patients suggest that the small intestine of

man responds to an increased dietary load in the same way as that of the rat (Booth *et al.*, 1961), for the jejunum absorbed more fat when the dietary fat was increased. Two of these patients (Cases 4 and 5, Fig. 3) had only 6 ft. of the proximal small intestine remaining, and there was a progressive rise in fat absorption with increase in the dietary intake (Fig. 3, Table I). However, the increased fat absorption in these patients was only achieved at the expense of an increased faecal fat excretion (Cases 4 and 5, Fig. 3). This suggests that, as also occurs in the rat, increasing amounts of fat may reach more distal regions of the small intestine when the dietary fat is increased. The results in the third patient (Case 2) are in keeping with this concept. This patient had lost only the terminal 8 ft. of the ileum and her remaining intestine was capable of absorbing normal amounts of fat from a moderate dietary intake (Fig. 1). However, when greater amounts of fat were given, the faecal fat excretion increased and steatorrhoea developed (Fig. 3), suggesting that some fat may reach the distal ileum and be absorbed there when the dietary intake is large.

Like the upper jejunum, the terminal ileum was shown to absorb fat well. Case 9, for instance, had only the distal 15 in. of the ileum remaining, yet he absorbed more than 35 g. of fat from this remnant of the distal small intestine (Fig. 2). Similarly, Case 8, who had lost the proximal 8 ft. of the jejunum, absorbed fat almost normally when given a moderate dietary intake (Fig. 2). In this patient, increasing the dietary fat resulted in a progressive increase in absorption and caused only a slight increase in the faecal fat excretion (Fig. 4); this contrasts with the steatorrhoea produced by similar diets in the patient with a comparable distal resection (Case 2, Fig. 3).

Repeated studies have demonstrated that when normal persons are given diets containing between 30 and 350 g. of fat daily, there is a slight increase in the faecal fat excretion, which may reach as much as 10 g. a day on the highest dietary intakes (Wollaeger, Comfort, and Osterberg, 1947; Annegers Boutwell, and Ivy, 1948), but in terms of the amount of fat absorbed there is a progressive increase in fat absorption as the dietary intake is increased. Masterton, Lewis, and Widdowson (1957) found that two polar explorers were able to absorb 263 and 276 g. of fat respectively from diets containing 273 and 285 g. of fat daily, diets which were designed to meet their high energy requirements. The results reported in this paper provide a rational explanation for this apparently unlimited capacity of the human small intestine to absorb fat. When a moderate dietary intake is given, it seems likely that fat absorption occurs predominantly in the jejunum

(Fig. 1). As the dietary load is increased, the amount of fat absorbed by the jejunum increases (Fig. 3). At the same time increasing amounts of fat escape absorption in the jejunum (Fig. 3) and presumably pass on into the ileum, where absorption may then normally occur, for, as shown by the results in Case 8, the distal intestine is also capable of absorbing increasing amounts of fat when presented with an increased load and very little fat passes through it unabsorbed (Fig. 4). The ileum therefore appears to become progressively more important as a site of fat absorption when the dietary fat is increased.

Since both jejunum and ileum are capable of absorbing fat well, and since both respond to an increased dietary load with an increased absorption (Figs. 3 and 4), it is not surprising that in man the amount of fat which can be absorbed is almost unlimited. Fat absorption must therefore be controlled by the appetite of the individual and not by any intramucosal mechanism such as that which regulates the absorption of vitamin B₁₂ (Glass, Boyd, and Stephanson, 1954; Swendseid, Gasster, and Halsted, 1954; Booth, 1958).

In conclusion, it appears that in man, as in the rat, the jejunum is the major area of fat absorption. As far as fat is concerned, the ileum seems to represent the main reserve of the small intestine which, like other essential organs such as the liver and kidney, is equipped to deal with far more than basic metabolic requirements. Although the ileum may be of relatively minor importance when moderate amounts of fat are taken, the results given in this paper suggest that it is likely to be of greater significance to those who enjoy gargantuan appetites. For individuals such as polar explorers who must take a high fat diet to meet high caloric requirements (Masterton *et al.*, 1957), a functioning ileum is probably essential.

SUMMARY

Fat balances were carried out in a group of patients who had undergone resection of varying amounts of the small intestine.

When moderate fat diets were given, resection of 6 or 8 ft. of the ileum did not interfere with fat absorption. Resection of larger amounts of the distal intestine caused steatorrhoea but a considerable proportion of the dietary fat was absorbed when only 4 to 6 ft. of the proximal intestine remained and some was absorbed even when all but the duodenum and proximal 8 in. of the jejunum had been resected.

The results of giving increasing amounts of fat in the diet to patients with resection of the distal small intestine indicate that the jejunum responds

to an increased dietary load with an increased absorption, but increasing amounts of fat escape absorption and are excreted in the faeces when the dietary fat is increased in such patients. These observations suggest that in man, as in the rat, increasing amounts of fat reach more distal levels in the small intestine as the dietary load increases. It seems likely that the jejunum in man is the major site of fat absorption when moderate diets are given, but the ileum probably becomes progressively more important with increase in the dietary fat.

Fat was absorbed well by a patient with a resection of 8 ft. of the proximal jejunum even when diets of up to 150 g. of fat were given. The terminal ileum can absorb fat, for a patient with only 15 in. of the terminal ileum remaining absorbed more than 35 g. from a diet containing 48 g. of fat.

We wish to thank Dr. F. Avery Jones for permission to carry out studies in Case 8, and Dr. Barbara Clayton for her kindness in allowing us to quote the results in Case 9. We also thank the physicians and surgeons of Hammersmith Hospital for their cooperation.

APPENDIX

Clinical details and results of other intestinal function tests in many of these patients were given at the International Congress of Gastroenterology at Leyden, 1960 (Booth and Mollin, 1961).

DISTAL RESECTIONS

CASE 1 A 30-year-old man developed gangrene of the terminal ileum as a result of a volvulus. Approximately 6 ft. of the terminal ileum was resected (surgeon's estimate), the ileum being anastomosed to the caecum. A barium follow-through demonstrated a normal pattern of the small intestine but very rapid transit, barium reaching the caecum within 15 minutes.

CASE 2 A 36-year-old woman had intermittent diarrhoea, passing two to three watery motions daily. Eight years before, laparotomy had revealed Crohn's disease of the terminal ileum and approximately 4 ft. of the terminal ileum and the ascending colon were removed. A recurrence two years later necessitated resection of a further 3 to 4 ft. of terminal ileum, end-to-end ileo-transverse anastomosis being performed. A recent laparotomy for an obstruction due to an adhesion had shown a well-functioning ileo-transverse anastomosis and no evidence of Crohn's disease. A barium follow-through revealed a normal small bowel pattern, barium passing into the colon in two hours.

CASE 3 A 40-year-old man had a 20-year history of tuberculosis involving first the right ankle joint and then the terminal ileum and caecum. Approximately 10 ft. of

the distal intestine had subsequently been removed (surgeon's estimate), the small intestine being anastomosed to the transverse colon by a side-to-side anastomosis. A barium follow-through revealed a normal pattern of the residual small intestine and the barium passed into the colon in two hours. There appeared to be a small blind end of the terminal ileum but there was no stasis within this loop.

CASE 4 A young woman aged 28 developed extensive gangrene of the distal small intestine caused by a volvulus. The affected part of the gut was resected, the surgeon estimating that approximately 6 ft. of the proximal intestine remained. End-to-side jejunocaecal anastomosis was performed. A subsequent barium follow-through revealed a normal pattern of the remaining small intestine, and barium reached the caecum within 20 minutes.

CASE 5 A 30-year-old woman had first developed Crohn's disease of the terminal ileum associated with a peri-rectal abscess 10 years ago. Resection of the distal small intestine had been carried out on four occasions. At her last operation, two years before, blind loops of the distal intestine were resected and the jejunum was anastomosed end-to-end to the transverse colon. The surgeon estimated that approximately 6 ft. of the jejunum remained. There was no evidence of Crohn's disease at this time. A barium follow-through revealed a normal pattern of the residual small bowel but the barium had passed into the colon by three quarters of an hour.

CASE 6 An imbecile hospital patient aged 24 years had developed a volvulus of the small intestine causing extensive gangrene two months before. The right side of the colon, together with all but the proximal 3 to 4 ft. of the jejunum (surgeon's estimate) were resected, end-to-end anastomosis being performed between the upper jejunum and the transverse colon. A barium follow-through was hampered by some delay in gastric emptying, but the pattern of the remaining small intestine was normal and barium passed into the colon within one and a half hours.

CASE 7 An 80-year-old widow had developed a thrombosis of the superior mesenteric artery causing extensive gangrene of the small intestine. The ileum and all but the proximal 8 in. of the jejunum were resected, but jejunal remnant being anastomosed end-to-end to the ascending colon. A barium follow-through revealed slight dilatation of the residual small intestine; some of the barium had reached the colon within five minutes. (This case has been reported in detail by Harrison and Booth, 1960.)

PROXIMAL RESECTIONS

CASE 8 A 71-year-old man had extensive jejunal diverticulosis requiring resection of 8 ft. of the proximal jejunum, the operation specimen being measured after the operation. End-to-end anastomosis was performed. A barium follow-through two years later revealed slight dilatation of the bowel immediately distal to the anasto-

mosis but no other abnormality. Barium had passed into the colon within four hours.

CASE 9 An 18-month-old child had undergone three successive operations on the small intestine for ileo-ileal intussusception. Extensive resections had been carried out, the stomach eventually being anastomosed to the terminal ileum. The amount of ileum remaining was estimated to be 15 in. (surgeon's estimate). A barium follow-through eight months later revealed slight dilatation of the remaining small bowel; barium reached the colon in one and three quarter hours. (This case has been reported in detail by Clayton and Cotton, 1961.)

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